



The CLEAN PAPER

WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

Thin, half-molten first crust: model kan níbi tí impacts, k̀ì í ̀̀ internal heat, ran Hadean

Earth first eon, Hadean, left almost no rock record. Modelling study yíì asks what crust would look like once impacts are included. Using stochastic declining impact-flux model and benchmarked crust/mantle heat-flow simulations, authors find impact heat could exceed Earth internal heat by at least order of magnitude for most Hadean, leaving thin crust (<~5 km) partially molten just few kilometres down — too weak, they argue, for plate tectonics, prone to recycling into mantle, explaining missing Hadean material. As impacts waned after ~3.9 Ga, lasting continental crust could form around when oldest felsic rocks appear — ‘likely not a coincidence.’ Conservative lower-bound heating makes qualitative result robust though exact numbers not fixed. Strong coherent model, not direct observation.

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Chapter kan nínú ìtàn Earth tí fẹrẹ̀ kò ní page kankan tó kù

Earth ni nìkan pílánẹ̀tì tí a mò pẹ̀lú continents — buoyant, silica-rich land tí gbogbo wa ní gbé lórí. Şùgbón bí first continents ẹ̀ form jẹ́ ọ̀kan lára oldest unsolved ìşòro nínú geology, fún brutal reason kan: ẹ̀rí fẹrẹ̀ parẹ̀ patapata.

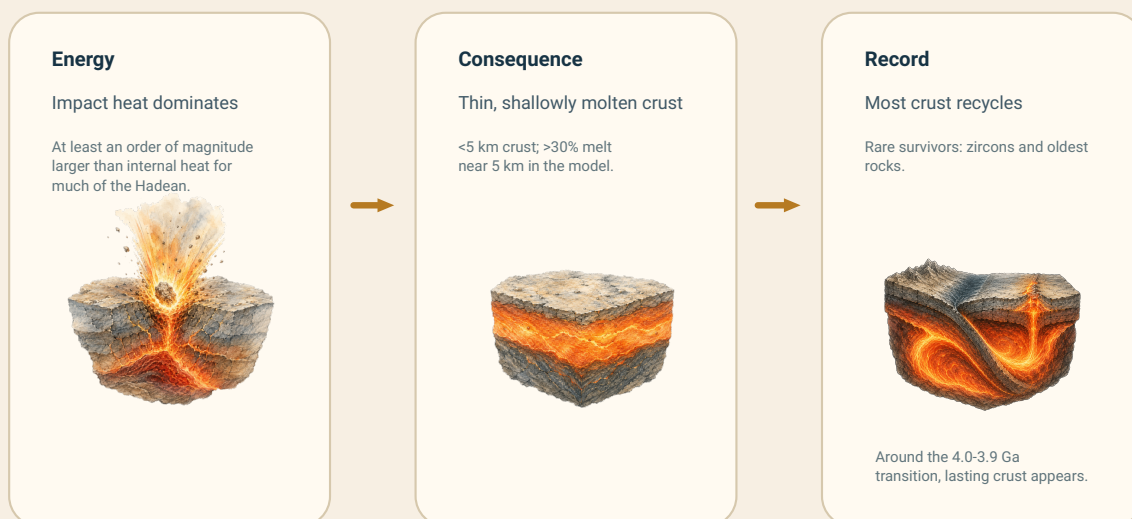
First eon Earth, Hadean, lọ láti birth pílánẹ̀tì dé nípa 4.03 billion years ago (Ga). Láti first half-billion years yẹn, fẹrẹ̀ kò sí nìkan tó survive. Oldest intact felsic (continental-type) àpáta jẹ́ around 4.03 Ga. Few rare basaltic àpáta reach ~4.2 Ga. Oldest ohun èlò of any kind jẹ́ scatter of zircon crystals — famously láti Jack Hills, Western Australia — dated to 4.4 Ga. Èyí ni entire archive tí Earth infancy: handful localities àti minerals tó ìwọ̀n bí sand grain.

ìwádíí yí kò fi tuntun àpáta kún archive. Ó ẹ̀ nìkan mǐràn: build physical àwòşẹ̀ tí ohun tí Hadean crust yẹ kí look like labẹ̀ physics yẹn, ó sì béèrè ìbéèrè tí most early-Earth àwòşẹ̀ leave out. Kí ló şẹ̀lẹ̀ tí o bá stop ignoring fact pé early Earth ní gba bombardment?

Answer àwọ̀n olùkòwé striking. Fún most of Hadean, heat delivered by impacts yóò have swamped gbogbo Earth internal heat, leaving crust thin àti half-molten — weak ju, gégé bí wọ̀n argue, fún anything like modern plate tectonics. àwòşẹ̀ ni, kì í ẹ̀ ìrántí. Şùgbón àwòşẹ̀ kan tí, fún once, ní try account fún violence of era tí ó describes.

A model of the Hadean, not a memory of it

The logic is thermal: impacts heat, crust melts, the archive erases itself.



Impact heat dominate àwòşẹ̀ agbára budget, thin shallowly molten crust recycle itself, enduring continental crust appears nìkan around 4.0–3.9 Ga transition. Èyí jẹ́ àwòşẹ̀ of Hadean, kì í ẹ̀ taara ìrántí rẹ̀.

Ohun tí àwọn olùkòwé ẹ

ẹgbẹ combine ingredients mẹtá tí a sáà keep separate.

Àkókò, **stochastic àwòṣe of impact flux** — rain of asteroids àti larger bodies hitting inner Solar System nípasẹ Hadean àti early Archean. Crucially, kì í ẹ old idea of single “Late Heavy Bombardment” spike. Ó jẹ flux intense early, **declines over àkókò**, large impacts arrive randomly (stochastically), kì í ẹ on schedule. àwòṣe rescaled láti lunar àti inner-Solar-System impact statistics, chosen to be consistent pẹ̀lú zircon age spectra àti available paleomagnetic ẹrí.

Elẹ̀ẹ̀kẹ̀jì, **geodynamic simulations** ti how heat moves nípasẹ crust àti upper mantle. Wọn lo benchmarked lattice-Boltzmann code (Planet_LB), run simple 1D temperature-versus-depth calculations àti full 2D convection snapshots of mantle at 4.1 Ga. Wọn include ordinary internal heat orísun — radioactive decay àti core heat — àti importantly, **magmatic advection**: heat carried upward by rising melt, which most crustal thermal àwòṣe omit.

Elẹ̀ẹ̀kẹ̀ta, **phase-equilibrium modelling** ti realistic early crust — hydrated Hadean metabasalt láti Nuvvuagittuq greenstone belt — láti isẹ out at what temperature àti depth àpáta like that starts to melt.

One methodological choice matter fún reading whole ìwé ìwádíí: òhùkòwé deliberately stacked deck *against* own conclusion. Wọn assume “nonchondritic” mantle (less heat-producing radioactive ohun èlò than chondritic reference), pẹ̀lú less than half internal heating of standard àwòṣe, conservative heating rates, ignore tidal heating láti young close Moon. Nítorí nàà calculated crustal temperatures jẹ **minima** — lower bounds. Tí anything, gidi Hadean hotter than modeled.

Ohun tí wọn rí

Impacts, kì í ẹ internal heat, dominate Hadean agbára budget. Tí impact heat integrate over àkókò, ó dwarfs internal contribution — by at least order of magnitude fún most Hadean. Nínú picture yí, impact heating, kì í ẹ radioactive decay, is pàtàkì engine driving early tectonism, fades to minor role nìkan lẹyìn nípa **3.9 Ga**.

Heat yẹn keep crust thin àti shallowly molten. Without impacts àti melt advection, àwòṣe gives Hadean crust partially molten nìkan below ~10–15 km. Add impact heat, melt zone rises dramatically: crust partially molten just **few kilometres down** (below roughly 2–5 km). Around 5 km depth, àwòṣe predict >30% melt — ipò where àpáta too weak to hold as rigid plate. At 5–10 km, temperatures ~1000–1100°C mean crust extensively molten almost regardless composition. Surviving solid crust yòò have been **thin, lábẹ nípa 5 km**.

Half-molten crust erases itself. Extensive melting lets dense iron- àti magnesium-rich ohun èlò sink àti separate, lighter silica-rich melts rise. Over àkókò this drives average crust toward sí i evolved, silica-rich compositions — produces felsic melt that lè crystallize zircon. Almost gbogbo thin crust yòò then recycle back sínú convecting mantle, consistent pẹ̀lú isotopic àkòsílẹ̀. Nínú àwòṣe yí, near-total absence of Hadean àpáta kì í ẹ gap — ó jẹ *prediction*. 4.2 Ga àpáta àti 4.4 Ga zircons are rare survivors of crust mostly destroyed as fast as it formed.

End of bombardment lines up pẹ̀lú first lasting continents. As bombardment waned across 4.0–3.9 Ga transition, crust lè finally thicken àti endure. Oldest surviving continental àpáta appear around kan nàà transition. òhùkòwé ipò carefully: that enduring continental crust appeared around this àkókò is “likely not a coincidence.”

àkólé inference wòn: labẹ conditions wònyí — thin crust, molten few kilometres down — **Hadean plate tectonics implausible**.

Wòn tún fi hàn why earlier işe reached opposite conclusion. Previous stochastic impact iwádíí rí nìkan minor ipa, <2.5% crust molten at any àkókò. Those iwádíí left out méjì things this òkan includes: global ipa of large impacts on melting deep mantle, àti upward transport of heat by rising magma. Put them back in, thermal picture changes drastically.

Kí ló dé tí àwòşe kì í şe ìrántí?

Gbogbo ohun lókè output of simulations, kì í şe reading láti Hadean àpáta — nítorí àpáta yẹn fẹrẹ gbogbo gone. Èyí kò make èsì weak, şùgbón ó define type èsì.

Chain: àwòşe of impact flux feeds àwòşe of mantle/crust heat flow, checked against àwòşe of how particular àpáta melts. Each link physically motivated, benchmarked where şeé şe — şùgbón whole thing coherent argument nípa what Hadean *gbòdò* have looked like given şeé gbà physics, kì í şe measurement of what it *did* look like.

Ìdí nìyẹn tí conservative assumptions matter. Nítorí ònkòwé choose lower-bound heating, still get pervasively molten shallow crust, qualitative conclusion — Hadean crust hot àti weak — robust to choices. What not pinned down: precise numbers — exact geotherms, melt fractions, crustal thickness. Read ìtòşonà lágbára, decimal places provisional.

Ohun tí èyí kò fi ẹrí múlẹ

- Kò taara observe Hadean crust. Almost no àpáta láti era; modelling èsì nípa physics implies, kì í şe measurement.
- Kò rest on “Late Heavy Bombardment.” Impact flux is declining stochastic òkan — no sudden spike required.
- Kò settle plate-tectonics debate. “Implausible” is lágbára physically grounded inference favoring hot stagnant-tàbí squishy-lid early Earth — tectonic mode genuinely contested.
- Kò fi ẹrí múlẹ impacts *caused* continents to appear around 4.0–3.9 Ga. Timing match lágbára association ònkòwé call “likely not a coincidence” — careful èdè fún compelling correlation, not demonstrated cause.
- Jack Hills zircons are **not** preserved continents. Rare grains fi hàn felsic ohun èlò àti water existed early; kókó àwòşe is crust that made them mostly recycled.
- Kò reconstruct full early Earth history. Simulations idealized — 1D profiles, 2D equatorial slices, impacts near equator, snapshots — not complete four-dimensional pílánẹ̀tì àwòşe.

Báwo ni ẹrí şe lágbára tó?

Fún central claim — impact heating first-order control on Hadean crust, keeping it thin àti shallowly molten — argument coherent, importantly conservative. Uses benchmarked geodynamics code, physically reasonable inputs,

lower-bound assumptions, integrates heat orísun most previous àwòṣe ignored. It also explains méjì stubborn facts at once: why almost no àpáta >~4 Ga survives (near-total recycling), why lasting crust appears as bombardment fades.



Jack Hills, Western Australia, seen by NASA ASTER. Zircons láti region include some oldest known surviving ohun èlò láti Earth's early crust, tiny clues láti an eon whose àpáta were mostly erased.

NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team fair-use

Limits equally clear: àwòṣe built on àwòṣe, anchored to sparse àpáta àkọsílẹ̀, most quotable conclusion “plate tectonics is implausible” is inference not observation. Right posture: lágbára, well-reasoned hypothesis that reframes Hadean, invites ìdánwò of assumptions — especially impact-flux àwòṣe — not closed ọ̀ràn.

Most useful summary kì í ṣe “this is what Hadean was like” tàbí “it’s just simulation.” Ó jẹ́: given ṣeé gbà conservative physics, early Earth lábẹ́ heavy bombardment yóò have thin, half-molten, self-recycling crust — ọ̀kan idea accounts fún surprising amount of little we lè actually see.

Kí nìdí tí ó fi ẹ̀ pàtàkì?

Popular image early Earth swings láàárín serene plate-tectonic water world like today, tàbí hellish lava pílánẹ̀tì. Work yí sketches physically motivated middle: thin crust repeatedly remelted láti few kilometres down, continually destroyed àti remade, impacts — not internal heat — setting terms.

Reframing yí does gidi iṣẹ́. It offers ọ̀nà iṣẹ́ fún méjì biggest facts of Earth infancy — near-total absence of àpáta àkọ̀sílẹ̀, timing first enduring continents — àti puts neglected ìlànà, impact heating, at centre. If holds, changes how we reason nípa when Earth became pílánẹ̀tì of stable continents, carries to other rocky worlds formed lábẹ̀ bombardments.

None requires àwòṣe to be last word. It needs be good hypothesis to ìdánwò — àti by tying to surviving zircon/iso-
tope àkọ̀sílẹ̀, it is. “Hidden Hadean” of title is kókó: era we lè mostly reach nìkan by modelling, nítorí era erased own ẹ̀rí.

Àkótán kedere

Earth first eon, Hadean (ṣáájú ~4.03 Ga), left almost no àpáta àkọ̀sílẹ̀. Modelling ìwádíí asks crust ìhùwàsí once impact heating included. Using stochastic declining impact-flux àwòṣe pẹ̀lú benchmarked 1D/2D crust/mantle heat-flow simulations including rising-melt heat, ò̀nkòwé rí time-integrated impact heat exceeded Earth entire internal heat by at least order of magnitude fún most Hadean. Consequence: thin crust (<~5 km), partially molten nìkan few kilometres down, >30% melt at ~5 km — too weak fún plate tectonics, which ò̀nkòwé call implausible. Such crust mostly recycle sínú mantle, explaining little surviving Hadean ohun èlò; as impacts waned across 4.0–3.9 Ga, lasting continental crust lè form around when oldest surviving felsic àpáta appear — “likely not a coincidence.” Because ò̀nkòwé deliberately lò conservative lower-bound heating, qualitative èsì robust though exact numbers not fixed. Strong coherent àwòṣe, not taara observation.

Àyèwò láìsí àṣejù

Ohun tí ìwé ìwádíí fi hàn: Nínú physically grounded simulations including impact heating àti magmatic heat transport, Hadean crust comes out thin àti partially molten few kilometres down, dominated by impact heat rather than internal heat, mostly recycled sínú mantle, àti — on àwòṣe — unable to ẹ̀ àtílẹ̀yìn fún plate tectonics.

Ohun tó ẹ̀e gbà sùgbọ̀n tí a kò fi ẹ̀rí múlẹ̀: Impacts are reason enduring continents appear around 3.9 Ga; Hadean stagnant/squishy-lid world rather than early plate tectonic; missing Hadean àpáta specifically nítorí molten crust recycled itself.

Ohun tí kò fi hàn: Direct measurement Hadean crust; settled plate-tectonics answer; demonstrated causal link bombardment fade → continents; Jack Hills zircons as preserved continents; complete àwòṣe early pílánẹ̀tì.

Main limitations: Almost nonexistent àpáta àkọ̀sílẹ̀; àwòṣe stacked on àwòṣe (impact flux → geodynamics → phase equilibria); impact flux representative uncertain choice; simulations idealized (1D/2D equatorial slices,

snapshots). Conservative lower-bound assumptions strengthen qualitative conclusion, not specific precision.

Confidence wo ni gbogbogbò reader yẹ kí ó ní? High that lábẹ́ ẹ́ẹ̀ gbà physics, heavily bombarded early Earth yóò have hot, thin, shallowly molten crust. Moderate that this makes Hadean plate tectonics unlikely àti explains missing àpáta àkọ̀sílẹ̀. Low fún claim that it *proves* exactly how continents formed tàbí when — lágbára conservative àwòṣe, not taara look.

Àwọn orísun

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